LBL-33312
UC-414

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

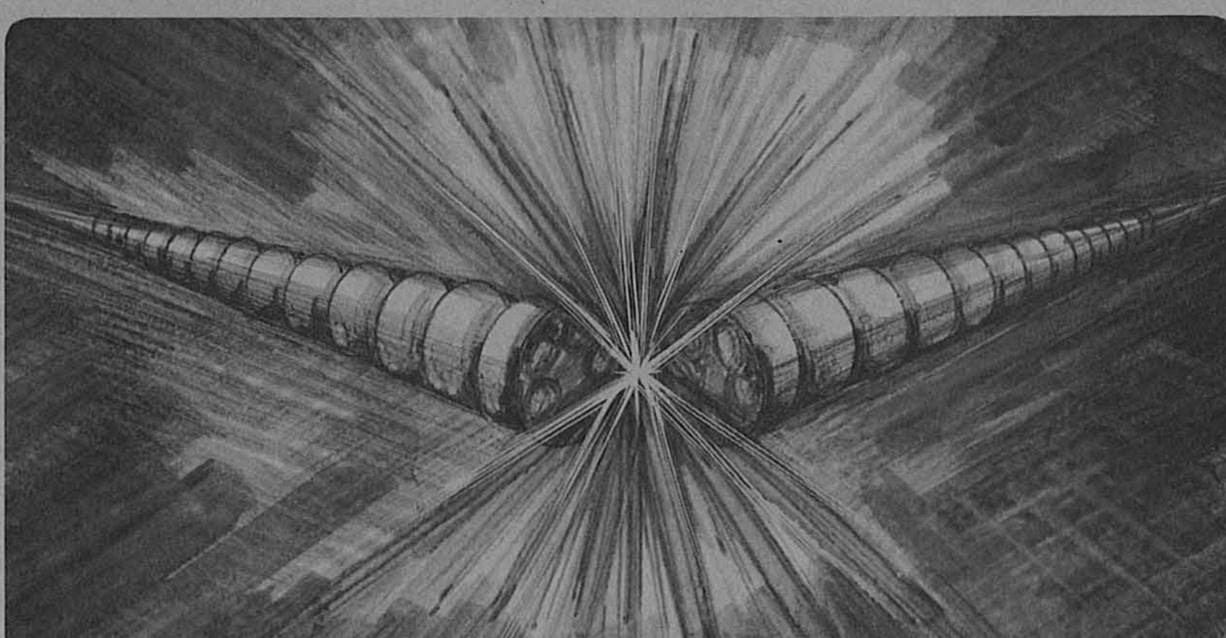
Accelerator & Fusion Research Division

Presented at the IEEE Particle Accelerator Conference, Washington, D. C., May 17–20, 1993, and to be published in the Proceedings

Measurements of Higher-Order Mode Damping in the PEP-II Low-Power Test Cavity

R. A. Rimmer and D. A. Goldberg

May 1993



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-33312
UC-414

Measurements of Higher-Order Mode Damping in the PEP-II Low-Power Test Cavity

R. A. Rimmer and D. A. Goldberg

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

May 1993

This work was supported by the Director, Office of Energy Research, Office of High Nuclear Physics, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LBL-33312
ESG-240

Measurements of Higher-Order Mode Damping in the PEP-II Low-Power Test Cavity

R. A. Rimmer and D. A. Goldberg*
Lawrence Berkeley Laboratory
1 Cyclotron Road, Berkeley, CA 94720, USA

Abstract

The paper describes the results of measurements of the Higher-Order Mode (HOM) spectrum of the low-power test model of the PEP-II RF cavity and the reduction in the Q's of the modes achieved by the addition of dedicated damping waveguides. All the longitudinal (monopole) and deflecting (dipole) modes below the beam pipe cut-off are identified by comparing their measured frequencies and field distributions with calculations using the URMEL code [1]. Field configurations were determined using a perturbation method with an automated bead positioning system [2]. The loaded Q's agree well with the calculated values reported previously, and the strongest HOMs are damped by more than three orders of magnitude. This is sufficient to reduce the coupled-bunch growth rates to within the capability of a reasonable feedback system. A high-power test cavity will now be built to validate the thermal design at the 150 kW nominal operating level, as described elsewhere at this conference [3].

I. INTRODUCTION

Impedances of higher order modes in the RF cavities can drive coupled-bunch instabilities in high-current storage rings. For the PEP-II ***B*** factory [4] we have taken the approach that the HOMs must be damped to a point where a practical broad-band feedback system can control the coupled-bunch growth rates. At the same time it is important to maximize the fundamental-mode impedance of the cavities to make most efficient use of RF power and to minimize the number of cavities and RF stations. The R&D effort, shared among LBL, SLAC and LLNL, has produced a normal-conducting cavity design [5,6] which uses a trio of dedicated damping waveguides to reduce the HOM impedances. The target was to reduce the longitudinal impedances to the order of a few kΩ, and the transverse impedances to a few hundred kΩ/m (comparable with the effect of the resistive-wall). The single-bunch parameters are typical of existing machines and not in the regime where microwave instabilities would be expected.

As a result of the ongoing R&D program some of the lattice and RF parameters have changed compared with those given in references 4,5 and 6. All of the changes make the RF design more conservative. Table 1 shows the current PEP-II RF system parameters.

Table 1
PEP-II RF system parameters
(including the effect of the 5% gap in the beam)

PARAMETER	HER	LER
RF frequency (MHz)	476	476
Beam current (A)	1.03	2.25
Number of bunches	1658	≥1658
Number of cavities	20	10
Shunt Impedance R_s (MΩ) [a]	3.5	3.5
Gap Voltage (MV)	0.93	0.60
Accelerating gradient (MV/m)	4.1	2.7
Wall loss/cavity (kW)	122	51
Coupling factor without beam (β)	7.5	7.5
Unloaded Q of cavity[b]	≥30000	≥30000

[a] $R_s = V^2/2P$
[b] with ports, at 40°C

II. LOW-POWER TEST CAVITY

A low-power test cavity (LPTC) has been fabricated, see figure 1, which was designed to show the loading of the HOM Q's and, therefore, the impedance reduction that could be obtained with the waveguide damping scheme.

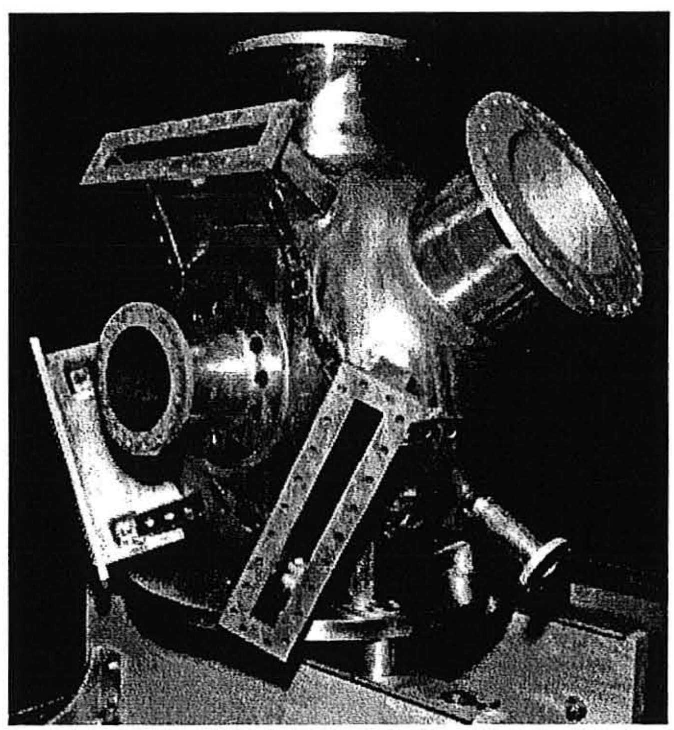


Figure 1. Low-power test cavity. The rectangular ports are for the HOM damping waveguides, the two large circular ports are alternative locations for a loop coupler.

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division of the U.S. Department of Energy, under Contracts DE-AC03-76SF00098 and DE-AC03-76SF00515.

To save cost, the quality of construction, though good, was not intended to show the ultimate Q of the fundamental mode that could be expected in the final cavities. Low-power mock-ups of the waveguide loads were made using ferrite powder in epoxy, cast into long tapered wedges. The load material was placed at the edges of the waveguides at least 36 inches from the cavity, as would be the case in a high-power design, to avoid coupling to the evanescent fundamental mode.

III. MEASUREMENTS

The cavity was excited with small electric-field antennas inserted into the beam pipes and a Hewlett-Packard 8510C network analyzer was used to measure the transmission response (S_{21}) between them. With all the apertures plugged or sealed, approximately flush with the cavity surface, the undamped modes of the cavity were seen as distinct peaks. The resonant frequencies were very close to those predicted by URMEL allowing easy identification of the modes.

Figure 2 shows the spectrum of modes from below the fundamental (TM_{010}) mode up to 900 MHz without damping. The lowest TE mode (TE_{111}-like), is visible, as are the TM_{011}-like longitudinal mode (the strongest monopole HOM), at about 770 MHz, and the TM_{110}-like deflecting (dipole) mode, at about 795 MHz. Figure 3 shows the same frequency span with the three damping waveguides attached. The fundamental mode is still strong while the HOMs are substantially damped. By changing the azimuthal position of the probes around the edges of the beam-pipes it is possible to enhance or reject the dipole modes relative to the monopole modes, and thereby measure the loaded Q's of overlapping monopole and dipole modes. It is also possible to discriminate between the two orientations of the dipole modes when there is a strong perturbation to the cavity such as the addition of the loop coupler.

Figure 4 shows more of the HOMs, between 900 MHz and 1.4 GHz, without any damping. The monopole and dipole modes are labeled. Figure 5 shows the same span with the

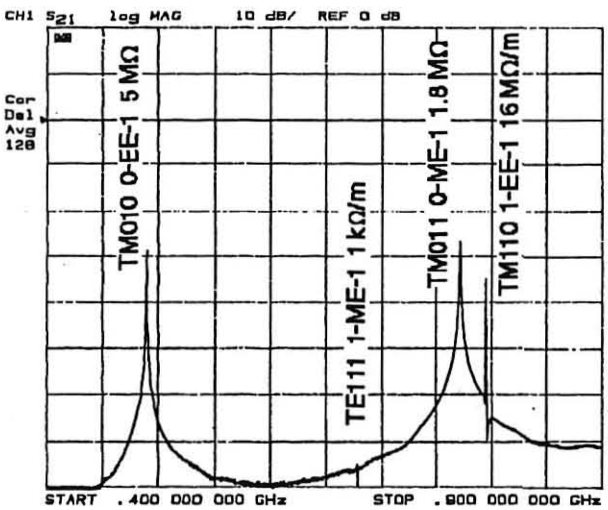


Figure 2. Fundamental mode and first three higher order modes in the LPTC without damping.

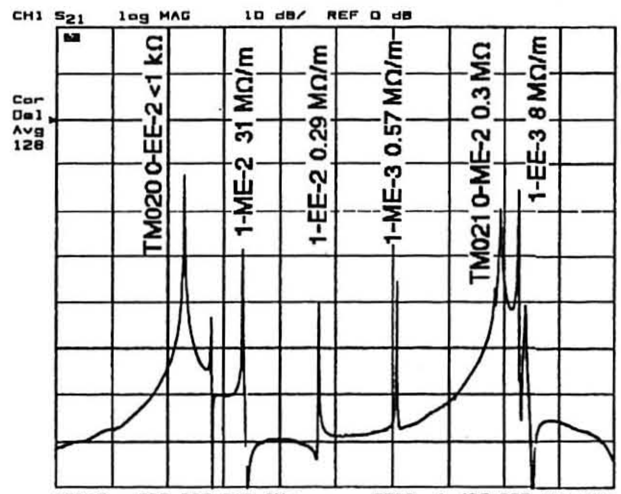


Figure 4. Higher order modes in the LPTC without damping, 0.9-1.4 GHz.

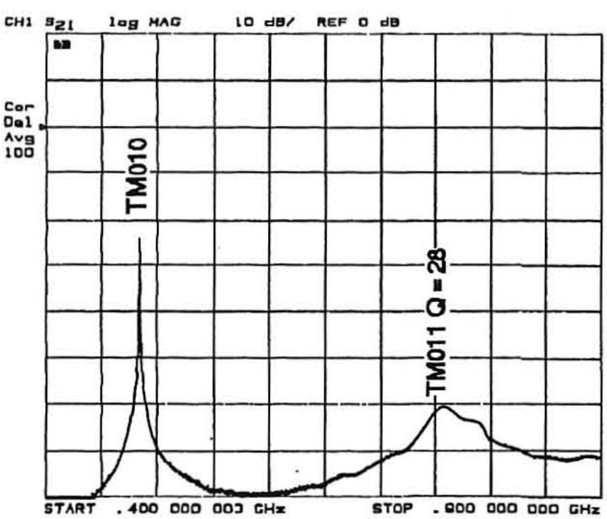


Figure 3. Fundamental mode and first higher order modes in the LPTC with three damping waveguides.

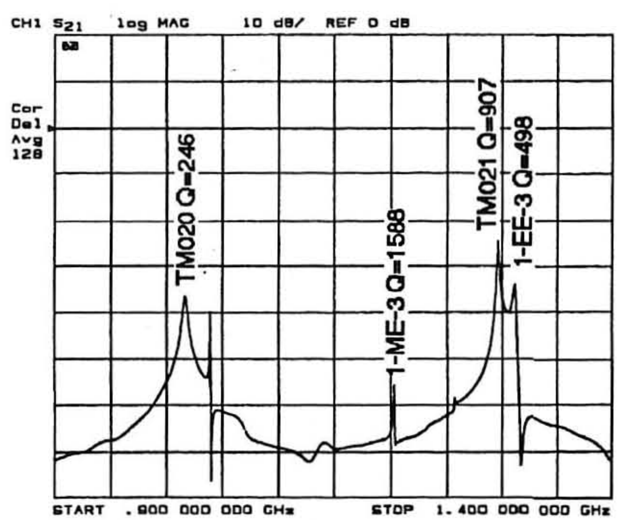


Figure 5. Higher order modes in the LPTC with three damping waveguides, 0.9-1.4 GHz.

three damping waveguides. Still visible are the TM_{020}-like monopole mode at about 1016 MHz, the TM_{021}-like mode at about 1296 MHz and the dipole mode at 1313 MHz. The residual impedances of these modes are within the capabilities of the feedback system. The results are similar for all the higher frequency HOMs up to the beam-pipe cut off. The residual impedances are shown in table 2 for the longitudinal modes and table 3 for the deflecting modes. A more detailed account of the results is available [7].

Table 2
Calculated and measured properties of longitudinal modes

Mode type	URMEL name	Calc Fo (MHz)	R/Q (Ω)	Meas F_L (MHz)	Meas Q_L	$R_{//L}$ (kΩ)
TM_{010}	0-EE-1	489.6	108.8	484	*31926	3472
TM_{011}	0-ME-1	769.8	44.97	758	28	1.26
TM_{020}	0-EE-2	1015.4	0.006	1016	246	0.001
	0-EE-3	1291.0	7.68	no	longer	visible
TM_{021}	0-ME-2	1295.6	6.57	1296	907	5.96
	0-EE-4	1585.5	5.06	1588	178	0.90
	0-ME-3	1711.6	4.75	no	longer	visible
	0-EE-5	1821.9	0.06	1821	295	0.018
	0-ME-4	1891.0	1.68	no	longer	visible
	0-EE-6	2103.4	3.52	2109	233	0.82
	0-ME-5	2161.8	0.02	2168	201	0.004
	0-EE-7	2252.2	1.21	2253	500	0.61

*note that model does not test ultimate fundamental-mode Q

Table 3
Calculated and measured properties of transverse modes

Mode type	URMEL name	Calc F_o (MHz)	$R/Q(kr)^2$ (Ω)	Meas F_L (MHz)	Meas Q_L	$R_{\perp L}$* (kΩ/m)
TE_{111}	1-ME-1	679.6	0.002	no	longer	visible
TM_{110}	1-EE-1	795.5	15.263	779	122	1.86
	1-ME-2	1064.8	27.590	no	longer	visible
	1-EE-2	1133.2	0.243	1141	112	0.65
	1-ME-3	1208.2	0.258	1203	1588	10.3
	1-EE-3	1313.2	5.861	1311	498	80.1
	1-ME-4	1429.0	2.873	1435	3955	341
	1-EE-4	1541.0	0.850	1554	59	1.62
	1-EE-5	1586.2	2.045	1588	178	12.1
	1-EE-6	1674.2	5.140	1674	2134	385
	1-ME-5	1704.4	0.096	1704	444	1.52
	1-ME-6	1761.9	0.104	1757	7129	27.3

* $R_{\perp L}=R/Q/(kr^2)\times Q_L$, where r in the beam pipe radius

IV. MACHINE SIMULATIONS

A simulation code has been used to study the growth rates of the longitudinal coupled-bunch instabilities that would be driven in PEP-II by the cavity impedances. The code includes a model of the beam dynamics, all of the residual HOM driving impedances from the cavities and a model of the proposed broad-band feedback system. Running the simulation for the longitudinal modes shows that the beam remains stable and that the large single-bunch transients that occur during injection are quickly damped down.

A transverse simulation program is being developed which is expected to show similar results for transverse beam motion since the deflecting impedances measured in the test cavity are reduced to the order of the resistive wall impedance.

V. CONTINUING R&D

Studies of the low-power test model are continuing, in particular to evaluate the effects of the loop coupler which may provide additional damping for some of the HOMs. The automated bead-puller is being used to measure the field profiles of the modes and hence the R/Q's, and to study the perturbations introduced by the various ports. The PEP-II R&D effort is now also focusing on building a high-power test model to prove that such a design can be conditioned and powered with up to 150 kW wall dissipation. High-power versions of the HOM loads are also being developed.

VI. CONCLUSIONS

The low-power test model has shown that it is possible to achieve the HOM impedance reduction required for PEP-II with the broad-band waveguide damping scheme. The worst HOMs have been damped by more than three orders of magnitude and the loaded Q's agree well with the calculated values reported previously. The detailed design of a high-power test cavity is well under way.

VII. ACKNOWLEDGMENTS

Although all the measurements were performed in the Lambertson Beam Electrodynamics Laboratory of the Center for Beam Physics at LBL, the design of the cavity has been very much a collaborative effort with the other participants in the PEP-II project. Thanks are due John Byrd at LBL for running the machine simulations.

VIII. REFERENCES

[1] "Reports at the 1986 Stanford Linac Conference., Stanford, USA, June 2-6 1986," DESY M-86-07, June 86

[2] D. A. Goldberg, R. A. Rimmer, "Automated Bead-Positioning System for Measuring Impedances of RF Cavity Modes", this conference.

[3] H. Schwarz et. al., "Design of a High-Power Test Model of the PEP-II RF Cavity", this conference.

[4] "An Asymmetric B-Factory based on PEP," Conceptual Design Report, LBL PUB-5303, SLAC 372

[5] R. Rimmer et. al., "An RF Cavity for the B-Factory", Proc. PAC, San Francisco, May 6th-9th, 1991, pp819-21.

[6] R. Rimmer et. al., "Higher Order Mode Damping Studies on the PEP-II B-Factory RF Cavity", Proc. 1992 Europ. Part. Accel. Conf., Berlin, Germany, March 24-28, 1992, pp 1289-1291.

[7] R. A. Rimmer, "RF Cavity Development for the PEP-II B Factory", Proc. Int. Workshop on B-Factories, BFWS92, KEK, Japan, Nov. 17-20, 1992, (PEP-II ME note 2-93, LBL-33360, ESG-242).